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AUTHOR Broudy, H. S.
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ABSTRACT

An address to the 1972 Convention of the National Association for Research in Science Teaching, discussions are included concerning failures of traditional science programs in the present academic enterprise for the purpose of developing new guidelines for science education research. Irrelevance of disciplinary courses, formal study, and compulsory schooling to societal situations are discribed as the major challenge to present curricula. Logically organized science disciplines are considered as designed primarily for the study of science but not for applicative use. The importance of problem-oriented science or theory to good practice is a matter open to discussion, and the ability of replicating or reinstating science knowledge is neither a necessary nor sufficient condition for an individual to attain good performance on his job or in his personal life. The primary use of the theoretical schemata of the disciplines by nonspecialists is interpretive in nature. Science education should not emphasize the replicative and applicative use of school learnings. The author concludes that research studies are needed to examine the interpretive teaching of science in schools and to build a conceptual context with the nature of life made intelligible. (CC)

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CAN RESEARCH PROVIDE A RATIONALE FOR THE STUDY OF SCIENCE?

by

H. S. Broudy
University of Illinois
Urbana Campus

ERIC Center for Science,
Mathematics, and Environmental Education
1460 W. Lane
Columbus, Ohio 43221

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CAN RESEARCH PROVIDE A RATIONALE FOR THE STUDY OF SCIENCE? *

by

H. S. Broudy
University of Illinois
Urbana Campus

These are the days of judgment, when schools at all levels are called upon to render an accounting. Presumably schools have entered into contracts, explicit or implicit, with a clientele to deliver certain services; presumably also some parts of the clientele believe that the promised services have not been delivered. Hence the demand for an accounting to students, school boards, and taxpayers.

Now a breach of contract is bad enough; but suppose schools are accused--as it seems at times they are--of making fraudulent contracts. Suppose schools promise, or allow the client to believe they promise, what, in the nature of the case, they cannot deliver. If the promise is made in good conscience, then the schools are fools; if made with deceit, then they are scoundrels. If they are both, then we are indeed in trouble.

A decade ago the contract to teach science, like Caesar's wife, was well above suspicion. What knowledge could be of greater worth in a technologically mature society? What more powerful symbols of intellectual rectitude than Galileo? What greater achievements of the mind than the speculations of the atomic physicist or the modern geneticist?

We are by now familiar with student defection from the hard sciences to the "caring" social sciences and the Humanities. Said Gerald Holton, Director of Harvard's Project Physics: "The whole problem of physics-course enrollment is nothing short of a national emergency . . . . the

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*Address, NARST, Chicago, April 6, 1972.

decline in physics enrollments is extending into the colleges."*

In the United States the percentage of male National Merit finalists choosing physics as a college major dropped from 18.80 to 11.16 during the 60's, and in engineering from 29.59 to 17.55.**

At the University of Illinois in 1970-71, for example, enrollments in astronomy were down 24% from the peak year (1966), down 81% in chemistry from the peak year in 1967; down 101% in mathematics from the peak year in 1969, and down 140% in physics from the peak year in 1965.

Moreover, the disaffection is not confined to the United States.***

I shall not burden you with the wealth of hypotheses advanced to account for the disaffection of the students--they range from the draft to the new hedonism--not because they are unimportant but rather because I believe they all point to a more fundamental disenchantment, one which challenges the rationale that has supported not only the study of science as a logically organized discipline, but the study of all disciplines so organized. Indeed, the challenge extends to the study of any theory, basic or professionalized. Inasmuch as the curricula of secondary schools, colleges, and professional schools, in large part, are theoretically oriented, and inasmuch as the guilds of scholars are the contrivers and custodians of theory, the challenge is directed at the very roots of the academic enterprise.

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*Gerald Holton, "Harvard Project Physics," Physics Today, 20, 31, 33-34 (March, 1967). Cf. also Laurel N. Tanner, "The Swing Away From Science," The Educational Forum, 36:2, 229-238 (January, 1972).

**D. J. Watley and R. C. Nichols, Career Decisions of Talented Youth: Trends Over the Past Decade (Evanston, Ill. National Merit Scholarship Corp., 1969), p. 5.

***Tanner, op.cit., pp. 229, 232.

What forms does the challenge assume:

(1) Charges that these disciplinary courses are irrelevant to social evils, e.g., as exemplified by racism, poverty, war, and alienation.

(2) Logically organized subjects are not directly relevant to nondisciplinary problems, and tend to bore students who are not interested in the subject matter as such.

(3) Charges that formal study (general and professional) correlates poorly, if at all, with life outcomes--especially vocational success.*

(4) Charges that compulsory schooling, i.e., formal study, is a fraud, because, hiding behind the slogan of equalizing educational opportunity, it supports the values of the middle class and its social dominance.

That these charges have not been without effect is witnessed by:

(1) The moves to the free university, interdisciplinary courses, and modification of curriculum requirements, degree programs, and examination procedures. The standard lecture-discussion, quizzes, final examinations, credit-hour complex is undergoing devaluation quite analogous to the "gold value" of the dollar.

(2) The claims of the professoriate to hegemony in the world of education are challenged by disadvantaged groups who reject a Platonic value hierarchy that enthrones abstract thinking and intellectual intuition as the supreme human excellence.

(3) A move toward more direct practical training and a reduction of the theoretical components of professional curricula.

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*Cf. Ivar Berg, Education and Jobs: The Great Training Robbery (New York: Praeger, 1970); Sterling Livingston, "Myth of the Well Educated Manager," The Harvard Business Review, January and February, 1971.

What does the traditional science program promise? First, as part of general education, it promises a more precise, critical, and fruitful way of thinking about the physical world. Science is regarded as essential to the armamentarium of a [illegible] coping with a modern technological society. Second, the study of science is held to be one of the more profitable avenues to the world of work in a technological society. We can say, I believe, that this has been the promise of all formal schooling in Western culture. But has science teaching delivered on these promises? Can it really do so?

When asked to explain why and how formal study of the intellectual disciplines would produce the promised life outcomes, the answer was "transfer," but transfer as interpreted by C. H. Judd rather than Edward L. Thorndike.* Judd argued that X was able to transfer a learning L to situation S to the extent that L was a general principle of which S was an instance. Thorndike, on the other hand, held that X transfers to S only those elements in L that are identical with those included in L. Put in a little different language, in transfer the learning input is <u>replicated</u> in the output, according to Thorndike; whereas in Judd's view, in transfer the relevance to S is deduced from L. The Judd theory is congenial to science because it is itself a paradigm of theory in which hypothetico-deductive thinking is central. Transfer by replicating identical elements seems more suited to explain the use of a skill or mastering a fixed body of information, e.g. learning the multiplication table, than for scientific problem solving. The current challenges can be interpreted, therefore, as a rejection of Judd's theory of transfer or, one might almost say, the rejection of the transfer power of theory in general.

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*I take it the explanation of transfer by formal discipline is no longer urged, at least not openly.

However, to argue that X "applies" scientific knowledge (L) to S--and this has been the standard claim of science teaching--is probably mistaken. For example, when my automobile refuses to start on a cold morning, I could, if pressed, state the general physical principles that would explain the wretched situation. But this does not help me unless I know more about the carburetion--it would also help if I could recognize the carburetor--and ignition systems of my car than I do know. The generalization that I do in fact apply is: When your car doesn't start, call the AAA garage man. In other words, the applicative use of disciplinary knowledge is rare unless supplemented by technical know-how or what we might call task-oriented knowledge, plus familiarity with the objects to be manipulated.

The complacency with which science educators promise that knowledge of science will result in application of science should be shattered not only by the lack of correlation between scholastic achievement in science and technological competence, but the inability of even well-educated men to cope with the failures of their household appliances. Only the specialized technologist applies science to nonscientific activity. Science as a logically organized discipline is designed primarily for the study of science.

A no less futile and perhaps fatal strategy is to acquiesce in the dogma that unless what has been studied can be replicated or reinstated as learned it will not function. In view of the large loss of course content in a relatively short time, the opponents of disciplinary study can easily show that it was a waste of time or that the subject was poorly

easily show that it was a waste of time or that the subject was poorly taught.* I shall return to the reasons for rejecting these conclusions shortly.

Before examining the reasons for the failure of the traditional science program to persuade its customers that it is delivering the promised goods, let us consider briefly the suggestion that if science were taught differently so as to motivate the student all would be well.

(1) Can science be taught heuristically so that its facts and principles can be discovered or induced by the student through experiment or ingenious teaching? Does science teaching have to be didactic and therefore boring?

(2) Can it be taught as an aspect of social problems, and thus insure its relevance for the concerns of pupils?

These two questions are often confused. As to the first, it is of course possible to teach science through discovery--that's the way science got made in the first place. Given sufficient time and ingenuity, it certainly could be done. But what would be the criteria for having done it well? I suppose it would be ability to use the basic concepts of the science in thinking about problems within that science, i.e., the same as those we use for testing the didactic version. So while teaching chemistry or biology heuristically may make the learning-teaching transaction more interesting and therefore more efficient, it does not represent a departure from teaching it as a logically-organized subject matter; its remoteness from existential relevance remains.

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*Thus from the fact that American adults do poorly on tests on historical information, it is inferred that history was poorly taught. The more just inference is that the average American citizen is not an idiot savant.

The case is different with teaching chemistry via the study of pollution or economics by studying famines in India; here relevance is guaranteed. The student would be learning science presumably as it is used in life situations, but the question (possibly for research) is how well science as a system of concepts can be learned in this way, and whether to function in life situations science has to shape the mind in its own conceptual molds. Another way of raising the question is to ask whether one has to study a science as a discipline before he can do interdisciplinary thinking.

The problem of transfer is mitigated but not eliminated by teaching science in school as it is used in life. One might in the twelfth grade, for example, practice certain procedures and arguments in group thinking about war. Will these discussions be replicated 10 years later, or will the students have to adapt what they learned to variants of the problem or to another kind of social problem, e.g., preservation of the environment? I take it that simple replication won't do. However, if we argue that from school discussions of interdisciplinary problems the student will derive generalizable knowledge or habits or forms of thought, then it is these forms that we have to stress and test. But if we do this, then we have raised the specter of the gap between theory and practice again, and we are once more confronted with the question: Is theory necessary for practice? Should we bother studying theory when we could be practicing the practice? I am not sure that even problem-oriented science or theory can be demonstrated as essential to good practice.

Let us suppose that we do teach task-oriented science or theory. This is done in professional curricula such as medicine, engineering, agriculture, and business management. The current challenges to professional

curricula are of two sorts: first is the questioning of the need of so much "basic" sciences as a preprofessional requirement--on the grounds that they are too remote from practice; second, the contention that even professionalized, i.e., problem-oriented theory, is superfluous for a correct professional performance. Since any performance, as a segment of overt behavior, can be imitated or hit upon by trial and error, without understanding why the performance is correct (which is supplied by theory), theory is neither a necessary nor a sufficient condition for a correct performance. If this is so, we can understand, first, why correct performances will not necessarily correlate positively or highly with the study of the theory, and, second, that practice of the expected performance will appear to be the most economical and direct training procedure. In other words, as Jerry Rubin would say, "Do it." If theory and performance practice are combined, as moderates would urge, the correlation between study and performance might rise, but if the increase is the result of the added practice, it does not help the case for theory.

If the study of theory in any form, but especially in its disciplinary form, is to be justified, evidence is needed for the hypothesis that learning <u>why</u> a rule of procedure is sound, which the study of theory makes possible, is a more efficient way of preparing people for life or the professions than an apprenticeship form of training that omits theory or greatly diminishes it. In other words, is the investment of the time and effort in theory prescribed by the academic guild warranted?

What sort of evidence would this be and how could research get at it?

1. That there is a difference between people who have had formal schooling and those who have not, and that we can recognize it, is a fact. But we recognize the difference intuitively. The evidence is not organized

and formalized. But research effort to establish the grounds for this intuitive faith empirically would do more for science study than 1000 monographs on the relative merits of teaching biology by methods A and B, valuable as these are.

2. We do not have the kind of evidence that supports what I believe is also a fact, viz., that some of the denigrators of theory are guilty of a species of cultural parasitism. This can take two forms: one is exemplified when a good student who has done well in standard courses in science argues that others can do without such study. Another form is illustrated when the critics forget that auto mechanics, for example, can do without the study of automotive engineering precisely because they are automotive engineers. The question is whether the theory that has been built into our technological system relieves all but a few individuals from the cognitive strain of studying theory themselves. Some evidence on this question, it seems to me, might be found in the history of developing countries that try to leap forward into a modern technological society by importing machinery and technicians from developed countries. Appropos of which an article in the January 7 issue of Science, Education and Science in China by Ethan Signer and Arthur W. Galston, is instructive.

Although candidly proclaiming that the aim of the new university is to get rid of an intellectual elite class, the Maoist philosophy of science is not wholly anti-intellectual. On the contrary, by its methods of admission, grading, and the organization of research, the new university is expected to induct the worker into theory, as well as forcing professors into practice. I have my doubts about Mao's belief that the (masses) workers under the guidance of cadres of Communist ideologists and Communist educated scientific cadres are the ultimate source of discovery

and verification of a scientific generalization. But there is little doubt that his aim is more in accord with our own aim of developing a scientific consciousness in all our people than is the sequestration of theory to a small social class--which is the road we shall travel, if the performance criteria are too narrowly conceived and the apprentice type of education is carried to an extreme.

3. The third kind of evidence for which research is needed is on the way science study as a school input functions when confronted by nonschool situations, especially such societal situations as the quality of the environment, the distribution of power in the social order, technology and social justice and the like. I shall say more on this point presently.

In Compact (February 1972) we are given some of the results and evaluations of the National Assessment on science literacy. The article by John K. Wolfe (p. 7ff) stresses the importance industry places on scientific literacy and suggests that an industry would like to locate in regions where scientific literacy was high. Further, he says, "The low level of science knowledge of the nonscientific public is appalling." He continues:

> For example, if I were a manufacturer of phosphate detergent, how would I describe it? I could describe it as having 8 percent phosphorus or 25 percent phosphate. If at the present time phosphate is a bad guy, then I'm going to put on my box that it has 8 percent phosphorus. If phosphate is a good guy, I'm going to try to make it 25 percent phosphate. I'm going to aim it emotionally so that the largest percentage of the public thinks my product is good. If 98 percent of the public doesn't know the difference between phosphate and phosphorus, the manufacturer is going to take advantage of that lack of knowledge. (p. 8)

I think we have a strong feeling that Mr. Wolfe is right, but if he is, then the students and educationists who say that study of science--scientific literacy--is irrelevant to the life outcomes which industry

expects from it are wrong. If, on the other hand, the lack of literacy is socially nonfunctional, then the low level is not appalling.

I suspect both National Assessment testers and Mr. Wolfe take for granted that the test of the functionality of science is the ability of the testee to reinstate "knowledge of fundamental facts and principles of science" or the knowledge of science content or about its method. This assumption is challenged by the arguments that knowledge is neither a necessary nor sufficient condition for good performance on the job or in society or in one's personal life. The critics of formal study of a discipline and Mr. Wolfe, I believe, are both mistaken but in somewhat different ways. The critics, because there is no necessary connection between knowledge and practice, mistakenly believe they can dispense with getting the knowledge; Mr. Wolfe is mistaken in believing that if the testee cannot replicate the knowledge it is appalling, presumably because it is not affecting his practice. Both share the belief that school learnings function in a situation only if they can be explicitly identified in that situation.

To argue that knowledge of or about science as a school input is necessary for its subsequent life use is one thing; that it functions by reinstating what was put in is a less obvious conclusion. Many a good physician has forgotten much of the content of the science courses he passes with A's in high school and college. We could use research on just how much is lost (let us say in five years after finishing medical school). But he does read and discuss medical literature that presupposes understanding the conceptual structure of biology, chemistry, and physics. Could a physician who had not studied these sciences read or discuss these materials? We know the answer, but we need empirical support for what is intuitively

obvious, viz., that we often know more than we can tell; that we use much of what we have studied in school but not in the detail we studied it. Indeed it may be the case that we can use the categorial schemata only by forgetting the details by which we learned the schemata, but without which we could not have learned them adequately.

For example, in studying oxidation and reduction we perform laboratory exercises, do problems at the end of the chapter, memorize equations and formulae, characteristics of elements and the like. How much of all this knowledge remains (if we are not specialists) 10 years after we have passed the chemistry course? Not much, but the general and generalizable principles of oxidation continue to determine how we think about a wide array of phenomena. We perhaps could not have learned the principle without the illustrative details--at that time the details were the cues to the principles. But a decade later the principles are themselves cues to understanding one or more of the contexts in which a societal problem, such as cleaning up Lake Erie, is couched. This is what Michael Polanyi has called tacit knowing*--when we use an input once learned explicitly as a clue to apprehending a larger context. Without having learned to read we could not interpret the instructions on a signpost, but to interpret a signpost it is essential that we do not become fixated on the post or the words in which the information is embedded. When we were learning to read, the words were at the center of our attention; in looking at the signpost, they are at the periphery. Put a bit differently, we might say that school learnings function in life by becoming means to contexts different from the content in which

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*The Tacit Dimension (New York: Doubleday, 1966, Anchor Books, 1967).

they were studied. In a disciplinary curriculum the subject matter ideally is an end in itself; we study physics to understand physics--I say ideally, because we may in school study physics to please our parents or to get a grade. If the disciplinary approach is to be justified, it is because if can operate in contexts on a different plane than that of a logically organized subject matter. Hence the use of subject matter tests to gauge the effect of studying science can be beside the point.

On the other hand, the formal study of science cannot be justified by applicational tests, i.e., by demonstrations that an individual having studied chemistry can remove stains from tablecloths and mercury from tuna fish. Solving a societal problem--or any existential problem--involves means of changing a situation--some sort of power made efficacious by apparatus and procedures which may exemplify principles, usually with the help of the inventor.

The rationale we have been using relies on the replicative and applicative uses of school learnings. The attacks on schooling can be interpreted as a rejection of that rationale, and this leaves us with the following alternatives:

(1) To ignore the attacks and continue to invoke the rationale.

(2) To reject the rationale and therewith disciplinary study on the grounds that it doesn't work.

(3) Reexamine the way science is used in nonschool situations and argue that this use is neither replicative nor applicative but interpretive.

The first alternative is the one the guild is taking, but conceding that science could be made more relevant and interesting by pedagogical

ingenuity. This ploy is bound to be beneficial because it will make the study of science more attractive to the student; it will not, however, lead to the kind of effects on nonschool life that the rationale claim for it.

The second alternative is unlikely because the scientific guild is concerned chiefly with science study as a means to doing research--pure or applied--in science. The members of the guild have little interest in the nonspecialist use of science, which they think is an attenuated form of their own use of it.

The third alternative can get us out of the difficulty of justifying science study, if we can get evidence to support the notion that in life we use science learnings interpretively. As citizens, we use scientific knowledge, methods, and attitudes not to solve (which requires technological knowledge) problems but to understand them. We use the theoretical schemata of the disciplines to classify, analyze, and to reconstruct the diverse contexts of societal problems. This is the primary use of knowledge by a nonspecialist, but we need research to map out the use of scientific schemata the citizen makes in reading and discussion.

Consider, for example, the following excerpt from an address on "Ecolibrium" by Athelstan Spilhaus (Science, 18 February, 1972, pp. 71 ff):

> Finally, all the efforts to maintain and increase choices (for the individual) use energy. Hence, if we are to continue to provide choice or increase choices, we must expect and plan to increase energy per capita in saving and clean ways. But to come full circle, when we accomplish these intermediate steps and increase energy per capita, if, at the same time, there is a continual increase in population, we will eventually arrive at a point where getting rid of the non-equilibrium heat generated on earth will become a problem. Inescapably, therefore, population limits which will maintain choice with no additional expenditure of energy are fundamental and most urgent.

Now this is not a technical passage, and you might agree that the average citizen could be expected to understand it. But how would we go about identifying the particular school learnings that make such understandings possible? On the other hand, aside from the mechanics of reading, what concepts are used that were learned in school? What about concepts such as "energy per capita," "non-equilibrium heat," and "getting rid of the non-equilibrium heat?" What domains of knowledge are relevant to further discussion of the problems raised in this passage? What enables the reader to make judgments of this type, viz., that economics, engineering, physics, etc., are relevant to them?

I submit that these educational questions cannot be answered by measuring the amount of school learnings the reader can replicate on a test in this, that, or all the subjects he studied in school; nor by testing the reader on whether he can apply this or that principle or fact studied in school to solving the problem of optimizing energy production and use. We need researched answers on the way school learnings are used interpretively, to build the conceptual contexts in which the nature of life problems become intelligible. What types of reading do we expect our graduates to do? Is it The New York Times, Life magazine, Science, Scientific American? Given materials at various levels of abstraction and complexity, could we not ascertain the scientific concepts and relationships that understanding these materials requires? Could we not analyze samples of discussions on ecology, weaponry, nuclear power, the industrial-military complex in the same way? Could we not test samples of our population to discover their blocks to reading and discussing such materials?

Such answers, I believe, will give to the study of science a rationale that can withstand the attacks now directed at its conventional defense.

*Although approaching the problem from an angle somewhat different from that of this paper, two articles by Lloyd G. Humphreys, a psychologist, bear directly on some of the issues involved: "Education in Science for Nonscientists," Chemical Education, 48:4, 217-218, April 1971 and "The Curriculum Never Changes--Only the Reasons for Offering It Change," Journal of College Science Teaching, 1:1, October 1971.